## A POSSIBLE PARTIAL EXPLANATION OF THE VISIBILITY AND BRILLIANCY OF COMETS.

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WITH AN ADDENDUM BY ELIHU THOMSON.

From a careful study of the so-called "shale-ball" meteorites described in my previous papers on the Meteor Crater of Arizona, I am impelled to make a suggestion that their peculiar and more or less uniform shape may give us a hint of at least a partial cause of the brilliancy of the head of comets and the gradually fading visibility of their tails.

It should not be forgotten that these so-called "shale-ball" meteorites have never before been described, and we would know little of their original shape were it not that the several hundred which have been found by us have been dug out of exceeding finely pulverized silicious dust, so abundantly found with larger rock fragments on the rim of the crater. This finely divided silicious dust is due to the pulverization of a portion of the 1,000-foot white or gray sandstone stratum during the passage through it of the meteoric mass which, by its impact with the earth, as is now proved, made the crater described in my previous papers. The great mass of this exceedingly finely pulverized "silica," so-called, most of which is so fine that it will easily pass a 100-mesh screen, is practically impervious to water, hence these shale-ball meteorites in many cases have retained their original shapes. As previously stated by me, they have no sharp corners, but are, generally speaking, either round, oval or pear shaped, and in fact closely resemble in shape ordinary river gravel. In nearly all cases oxidation has penetrated from the outer surface inward for varying distances, but in most cases not sufficiently far to make it impossible to know what the original shape of the iron mass was when it fell to the earth and was imbedded in the outpouring from the crater, like flour from a barrel, of the finely divided silica dust commingled with rock fragments. In all of the many thousands of iron meteorites found around the crater only one aerolite, or perhaps more accurately siderolite, has been found. This was found by me on June 24, 1905. Inasmuch as by far the greater part of this aerolite was stony in nature, it had

yielded but very slightly to oxidation since it fell upon the earth. It is interesting to note, however, that all of its edges were rounded as if they had been subjected to abrasive action, but it was not as perfectly rounded or oval in shape as the great majority of the iron meteorites. If it fell at the same time as the cluster which made the crater, as I now think is probable, possibly this was due to the fact that it had been gathered up by the iron-headed comet in its passage through space and had not been a member of the cluster for as long a time as its iron companions.

The abrasive action between these masses of meteoric material composing the comet's head, even though it is less than any grinding action that we can conceive of owing to the fact that the mass travels through the ether of space, has, I would suggest, something to do with the visibility of comets. Inconceivably gentle abrasive action may be sufficient to wear off infinitesimal particles of matter, considering the enormous periods of time available. If so, may it not be that the attrition between the masses of meteoric material, for example masses of iron, not only possibly causes a disturbance of the ether where the grinding or milling action takes place, but literally fills the space in and around the head of the comet with exceedingly fine particles of cometary dust? May not these fine particles of matter, possibly electrified, also form the so-called tail as they are swept away from the main body of the comet travelling through space? The explanation of the tail pointing away from the sun is somewhat difficult on this theory, but the difficulty disappears if we can conceive the particles to be so infinitesimally small and so wanting in weight as to be affected by the light waves of the sun and to be driven by them in a direction away from the sun.

There can be no doubt that all the so-called "shale-ball" iron meteorites so far discovered by us in the material forming with the upturned edges of the limestone and sandstone strata the rim of the Arizona crater show evidence of what seems to have been abrasive action. The inference is unavoidable that they have been subjected, during perhaps billions of years, to such action, inconceivably slight, it is true, but nevertheless sufficient to finally reduce them to the shapes in which we find them. It is evident that the abrasion was not produced by their passage through our air. May they not be in fact "celestial cobblestones," and may not the milling action when they rub against each other, even very gently, account, in some way, not perfectly understood, for not only what we term the brilliant head of a comet but for its tail as well?

This is only a theory, but the inference seems to be justified. The rounded shape common to this kind of meteorites is a fact which must be explained, and the only reasonable explanation is that it has been due to mutual abrasion. The largest mass of meteoric iron of this description so far found by us weighed over 100 pounds. I have no doubt, however, that many of them composing the cluster which formed the head of the very small comet, which produced by its impact with the earth what we know as Meteor Crater, were much larger. Evidence that many others fell upon the earth around the crater is to be found in the fact that the plain round about is strewn with what is locally known as "iron-shale," certainly due to the decomposition of these "shale-balls," it being merely oxidized meteoric iron. A great many thousand pieces of this "iron-shale" have been found around the crater, on all sides of it, but most abundantly to the N.N.E., the direction from which the cluster is supposed by those of us who now recognize the true origin of the crater to have approached the earth. This variety of meteoric iron, as I have previously stated, decomposes very much more rapidly than any other meteoric iron ever discovered, owing to the fact that it contains appreciable quantities of chlorine. That thousands of "shale-balls" were strewn about the crater a moment after the impact there can now be no reasonable doubt. It is a remarkable fact, however, that no piece of the so-called "iron-shale" has ever been found which is not slightly curved, similarly to the "iron-shale," found on the outside of the slowly decomposing "shale-ball" meteorites which lie deeply imbedded in the silicious dust forming a great portion of the rim of the crater. Most of the latter have iron centres and the "iron-shale" surrounding them are merely the layers of iron oxide still adhering to the central iron mass. When we compare the two, the pieces of "iron-shale" found on the surrounding plain show conclusively by their shape that the so-called "shale-ball" meteorites from which they were derived were originally more or less globular in shape.

Saturn's rings are now believed to be composed of meteorites, but upon the theory which I have advanced there is possibly no milling or grinding action taking place between them such as may take place for some unknown reason in the head of a comet. I may, however, easily be in error as to this.

If the lunar craters and the Arizona crater have had a common origin, as now seems very probable, there can be no doubt that our knowledge of cosmogony has been greatly advanced by the discovery of the

origin of the Arizona crater and that there is much stronger reason now than ever before to believe in the general correctness of Chamberlin's and Moulton's theory of the building up of planetary systems. It is calculated that some 2,000,000 meteorites reach our atmosphere every twenty-four hours, and it is highly probable that in the early history of the earth it was abundantly bombarded by cometary bodies, that are probably, after all, merely masses of meteoric material which have gotten together and in some way not known to us have assumed orbits of their own. It would seem, however, that most of them, as well as most of the meteoric material originally forming the nebula out of which our solar system has been built up, have long since been gathered into the sun, its planetary bodies or the moons revolving about them. Our moon, having been without an atmosphere for perhaps a great many millions, if not billions, of years, shows evidences of some of the more recent accretions to its mass, outside of the more or less steady rain of cosmic dust. Its numerous craters probably merely represent the gathering in of cometary bodies or clusters of meteorites, for they are apparently exactly similar to our Arizona crater, except that most of them are vastly larger.

If this theory of the building up of solar systems be correct, is it not wonderful to reflect that when one holds in the hand one of these pieces of meteoric material he is probably holding something older than our sun, our own earth, or any of the planetary bodies which with their moons revolve about the sun? That is to say, he is literally holding, practically unchanged through countless eons of time, a part of the nebula out of which our solar system was constructed and which nebula in turn probably represented the wreckage of a previously existing system.

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ADDENDUM BY ELIHU THOMSON.

The following comments on the above paper were received by Mr. Barringer from Prof. Elihu Thomson:

I have your letter of June 14, enclosing a communication which you are thinking of sending to The Academy of Natural Sciences of Philadelphia. I think there is little question that the explanation put forward in your paper as to the rounded shape of the shale-ball meteorites is the true one. I have, in fact, often spoken of the inevitable readjustments that may take place in a small cluster revolving around the sun and the attrition between the parts as accounting for the steady production of very finely divided material

driven away from the nucleus by the pressure of light. In fact, I have talked of this very thing with the astronomers, and they have not raised any objections to it. I take it that what happens is about this—at least, this is in accordance with my idea of what happens:

When the comet is far removed from the sun and consists, as it probably almost always does, of a nucleus of fairly heavy pieces surrounded by lighter masses, they are, on account of the cold of space, at a very low temperature, and what little gravitational effect is produced is just sufficient to prevent them being scattered. They are free, at the far distance from the sun, from anything like tidal action. The cluster might even be revolved without being distorted by disturbance of the parts. Should they pass within range of the gravitational effect of Jupiter and have the path slightly disturbed thereby, there would necessarily be (by the slipping of the parts over each other) an attrition or grinding action taking place, and this would continue so long as the body was within the range of the disturbing planet. The same would be true of the cometary clusters passing towards the sun and around it (making a so-called perihelion passage), except that there would be some little difference. In this case, the particles of fine material, the result of the grinding, and held in the cluster, would now be free. The manner of this freeing can easily be understood. The face of the mass of the cluster on the side toward the sun would undergo a warming or heating process. This would result in the evolution into the vacuous space of whatever vapors or gases, however rare they might be (originally occluded in the face of the masses of the cluster), especially from the warmed surfaces. This would amount to a flowing of gas or evolution of gas on the side toward the sun which would lift the dust particles away from the mass, and the very fine particles would thus be free to be driven back by the light pressure to form a tail. It is an old idea that during this process if the sun were highly electrified electrical actions would take place, electrical readjustments to the increasing actions of the sun, but I think it doubtful whether the tail is much, or anything, of an electrical nature, for the reason that the vacuous space in which the tail moves is so high a vacuum that no conduction would be possible.

I am inclined to think that whatever actions of temperature or electrical actions occur would be practically within the nucleus or near it. The spectroscope shows that as the comet approaches the sun gas is actually evolved; and the spectra of cyanogen and carbon monoxide are common in comets, and possibly also hydro-

carbon spectra in some cases. The luminosity of the tail, which, it must be borne in mind is extremely low, according to any way of rating it, is, I think, amply accounted for by the great depth of space in which the fine matter exists and the solar light of high intensity reaching this fine matter: a pure case of diffusion from fine particles. As to cosmic dust not reflecting sunlight as does fine cometary dust, the following explanation, it seems to me, is ample. We see things by contrast. Even if there was a slight luminosity in space, it would simply form a background for the comet's tail, which would be more luminous and more dense in dust. The astronomers have long suspected a very thin veil of dust in the sky, of dust under illumination. The sky is not, in fact, absolutely black. It is black by comparison. Of course, it cannot be expected that ordinary meteorites should ever be seen in the sunlight. They are too small or too far apart. Only when they reach a considerable size do they produce any impression as single spots of light. Witness the asteroids or the little planet Eros, which probably is miles in diameter and yet is difficult to detect.

My idea is that the continual readjustment of the position and relation of the parts within a small cluster, or even within a large cluster forming a large comet, will account for practically all that occurs in the head of the comet and in the tail.

This tail will always point away from the sun. It will curve backwards, for although the particles move in a straight line from the sun, it will curve backwards owing to the progress of the nucleus around the sun. The tail will continue to be formed so long as the disturbing actions occur, and it will fade away as the comet gets so far from the sun as not to be distorted or disturbed. If the comet is not otherwise lost, this action will continue on from the action of the sun with a constant reduction of mass and the final diffusion of the material composing the comet.

Your statement in relation to the aerolite of a stony nature which you found is very interesting to me, as I had not heard that you had found any such stony meteor. It is quite easy, however, it seems to me, to account for it as a survival of perhaps many others present in the cluster. The stony meteorites will naturally be sifted out from the iron meteorites in the flight of a meteor through our atmosphere. They would not only be crushed by air pressure on their relatively greater area per unit of mass, but on account of their lower specific gravity they would not have the ability by momentum to force their way as far. Their relatively

low momentum and greater air resistance in proportion to their mass would make them early losers in the race, while the air pressure encountered would usually smash them into small pieces.

I think it quite probable that the stony matter of the earth is merely an outer layer over an iron centre, and in the smash up of any body due to partial collisions or actual collisions the stony matters must be dissipated, as well as the iron masses, to be gathered up again by the approach near to a large gravitating body like a planet or a sun.

Your expression of "celestial cobblestones" is very expressive and pertinent to the case of the shale-ball masses, and your observation that pieces of apparently broken-up shale-balls are curved indicates a similar origin for all of them. The flight of a cluster of small and large meteoric masses, more or less rounded through our air, would naturally be a sifting-out process, as the smaller bodies would lag behind in the flight.